10/524186
DT05 Rec'd PCT/PTO 08 FEB 2005

Description

Method of fabricating an electromagnetic-radiation-emitting semiconductor chip and electromagnetic-radiation-emitting semiconductor chip

The invention concerns a method of fabricating an electromagnetic-radiation-emitting semiconductor chip based on AlGaInP, comprising the method steps of: preparing a substrate; applying to the substrate a semiconductor layer sequence comprising a photon-emitting active layer; and applying a transparent decoupling layer, particularly a decoupling layer comprising $(Ga_x(In_yAl_{1-y})_{1-x}P$, wherein $0.8 \leq x$ and $0 \leq y \leq 1$. The invention also concerns an electromagnetic-radiation-emitting semiconductor chip based on AlGaInP, comprising a substrate, a semiconductor layer sequence applied to the substrate and comprising a photon-emitting active layer, and a transparent decoupling layer disposed on the active layer and comprising GaP.

The present application claims the priority of German patent application DE 102 39 045.2, filed August 26, 2002, the disclosure content of which is hereby expressly incorporated by reference.

In this context, materials based on InGaAlP include in particular all mixed crystals whose composition falls under the formula $(Ga_x(In_yAl_{1-y})_{1-x}P$, wherein $0 \leq x \leq 1$, $0 \leq y \leq 1$ and $x + y \leq 1$. Electromagnetic-radiation-emitting semiconductor chips based on AlGaInP include all semiconductor chips in which the semiconductor layer sequence in which an electromagnetic-radiation-generating layer is disposed comprises at least a substantial proportion of InGaAlP-based material and the properties of the radiation emitted by the semiconductor chip are at least substantially determined by the InGaAlP-based material.

This material based on InGaAlP need not necessarily have a composition that is mathematically exactly that of the above formula. Rather, it can include one or more dopants and additional constituents.

The AlGaInP material system is very attractive for use in light-emitting diodes (LEDs), since its bandgap can be adjusted by varying the Al content over a broad range of 1.9 to 2.2 eV. This means that LEDs can be made from this material in the color range of red to green.

To fabricate such LEDs by epitaxy, a substrate is needed on which the various semiconductor layers in the sequence can be deposited insofar as possible in monocrystalline form. Such a substrate for the epitaxy of AlGaInP-based LEDs should meet the following conditions:

- it must have a lattice constant that enables the material systems AlGaInP and AlGaAs to be deposited in monocrystalline form,

- it must remain sufficiently solid at the process temperatures used, and

- it must be available commercially in sufficiently good quality.

All the aforesaid conditions are met by GaAs substrates. GaAs is consequently used throughout the world as a substrate for AlGaInP LEDs. From the standpoint of economical LED manufacture, however, GaAs substrates have the disadvantage of being expensive and containing arsenic. Other substrate materials either have a high lattice mismatch or are not adequately suited for the usual process steps.

The object of the invention is, therefore, to provide a method of the species cited at the beginning hereof that permits the technically simple and low-cost fabrication of a radiation-emitting semiconductor chip based on AlGaInP.

This object is achieved by means of a method having the features of Claim 1. Further advantageous embodiments and improvements of the method will emerge from dependent Claims 2 to 8.

An electromagnetic-radiation-emitting semiconductor chip that can be fabricated according to the method of the invention constitutes the subject matter of Claim 9. Advantageous embodiments and improvements of the semiconductor chip of the invention form the subject matter of dependent Claims 10 and 11.

It is provided according to the invention, in a fabrication method of the species cited at the beginning hereof, that the substrate is substantially composed of germanium and that the transparent decoupling layer is applied at low temperature. Germanium has a lattice constant that is readily tolerated with the material systems AlGaInP and AlGaAs and is available commercially in high quality. Moreover, the price of a germanium substrate is only about half the price of a GaAs substrate, resulting in great savings potential for the production process.

The lower thermal stability of germanium compared to GaAs is taken into account by the fact that the especially critical step of growing the gallium-phosphide-containing transparent decoupling layer is performed at a low temperature at which the germanium substrate still has adequate solidity and a low vapor pressure.

In a preferred embodiment of the method of the invention, it is provided that the transparent decoupling layer is applied in the form of a phosphorus source, using tertiary butyl phosphine (TBP, $(C_4H_9)PH_2$). Conventional LEDs based on AlGaInP typically involve the use of a light-decoupling layer of GaP which is deposited epitaxially, using phosphine (PH_3), at a temperature above 800°C. Such reactor temperatures are too high for processes involving germanium substrates. The use of tertiary butyl phosphine as a phosphorus source, however, makes it possible to deposit a high-quality light-decoupling layer at much lower process temperatures.

In particular, it is especially advantageous to apply the transparent decoupling layer at a temperature below 780°C, preferably below 750°C.

It is particularly preferred if the transparent decoupling layer is applied at a temperature of about 700°C.

It is also frequently advantageous to apply the transparent decoupling layer using trimethyl gallium as a gallium source.

Given a typical lateral dimension for the active layer of $A = 250\ \mu m$, the thickness of the decoupling layer is then selected to be between about 1 μm and about 10 μm, preferably between about 2 μm and about 10 μm.

In an advantageous embodiment of the method of the invention, the transparent decoupling layer is grown by metal-organic vapor-phase epitaxy (MOVPE).

During the growth of the transparent decoupling layer, the V:III ratio is advantageously adjusted to a value of 5 to 20, preferably about 10.

Further advantageous embodiments, features and details of the invention will emerge from the dependent claims, the description of the embodiment example and the drawing.

Further advantages, preferred embodiments and improvements of the invention will emerge from the following explanation of an embodiment example in conjunction with the drawing. Only the elements essential to an understanding of the invention are represented.

The single figure is a schematic diagram of a sectional view of a radiation-emitting semiconductor chip according to an embodiment example of the invention.

Figure 1 is a sectional view of an AlGaInP-based LED chip 10 generally denoted by 10, shown in schematic representation.

The LED chip 10 comprises a germanium substrate 12 on which a semiconductor layer sequence 14 is formed. In the embodiment example, the semiconductor layer sequence 14 is a double heterostructure comprising an active, photon-emitting, AlGaInP-based n-type layer 22 enclosed by an AlGaInP-based n-type confining layer under the active layer an AlGaInP-based p-type confining layer over the active layer. Structures and layer sequences of this kind are known to the skilled person and therefore will not be described more thoroughly here. The aforesaid layers are doped to the desired impurity content with suitable p-dopants such as Zn, C or Mg or with suitable n-dopants such as Te, Se, S and Si, respectively, as known in the art.

The active semiconductor layer sequence 14 can alternatively comprise a multiquantum well structure, as also known, for example, from the prior art.

Applied to the p-type AlGaInP confining layer is a thick light-decoupling layer 16 of $(Ga_x(In_yAl_{1-y})_{1-x}P$, wherein $0.8 \leq x$ and $0 \leq y \leq 1$, or of GaP. Since the bandgap of the decoupling layer is greater than that of the active layer, light-decoupling layer 16 is transparent to electromagnetic radiation generated in active layer sequence 14.

In the case illustrated, the necessary current for powering the LED chip is supplied to the active layer of the LED chip 10 via a front-side contact 18 and a back-side contact 20. However, the contacts can alternatively be arranged otherwise than as explicitly shown in the embodiment example.

Light-decoupling layer 16 is applied by organometallic vapor-phase epitaxy (OMVPE). Tertiary butyl phosphine (TBP,$(C_4H_9)PH_2$) is used as a phosphorus source and trimethyl gallium as a gallium source, and a V:III flux ratio of about 10 is selected. The growth temperature in the embodiment example is 720°C, a temperature at which the germanium substrate is still sufficiently solid in the reactor.

In the embodiment example, layer sequence 14 has a cross section of 250 μm x 250 μm and a layer thickness of between 2 and 10 μm.

The features of the invention disclosed in the foregoing description, in the drawing and in the claims can be essential to the practice of the invention both individually and in any combination.